Marginal Expense Oil Well Wireless Surveillance MEOWS - Phase II

(Aka Marginal Expense Real-Time Wireless Surveillance of Rod Pumps Using Flow Signatures)

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Dr. Mason M. Medizade[1], *Petrolects, LLC*
Dr. John R. Ridgely[1], *Petrolects, LLC*
Mr. Donald G. Nelson[2], *Vaquero Energy*

[1] Primary Contractor
Petrolects, LLC
128 Twin Ridge Drive
San Luis Obispo, CA 93405
(805) 543-1010

[2] Award Recipient and Project Director
Vaquero Energy
P. O. Box 308
Edison, CA 93220
(661) 363-7240

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Abstract

A marginal expense oil well wireless surveillance system to monitor system performance and production from rod-pumped wells in real time from wells operated by Vaquero Energy in the Edison Field, Main Area of Kern County in California has been successfully designed and field tested. The surveillance system includes a proprietary flow sensor, a programmable transmitting unit, a base receiver and receiving antenna, and a base station computer equipped with software to interpret the data. First, the system design is presented. Second, field data obtained from three wells is shown. Results of the study show that an effective, cost competitive, real-time wireless surveillance system can be introduced to oil fields across the United States and the world.

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The following items are confidential sections of this report. They are on file with the DOE in hard copy format, but are not released to the public due to the patent-pending nature of this new technology.

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Introduction

The primary goal of this project was to develop a Marginal Expense Oil Well Wireless Surveillance (MEOWS) oil production monitoring system to improve the efficiencies of individual producing wells in the Edison Field, Main Area of Kern County in California. Through a 1999 grant from the Department of Energy, Vaquero Energy embarked on a novel work, MEOWS Phase I, to help minimize electricity consumption, optimize oil production, and reduce surveillance costs. Details of MEOWS Phase I are published two reports: 1) DOE Report DE-FG26-99BC15246 and 2) SPE 62865.

Shallow, heavy oil wells in California are sometimes operated in a "pump-off" condition, with fluid only partially filling the pump body, due to reservoir and well conditions. When a well is pumped off, the pump plunger pounds into the surface of the fluid as it moves down through gas, and then hits liquid. Fluid pound mechanically transmits vibration through the rod string, through the polish rod clamp, through the carrier bar, through the bridle, through the horse head, and into the pumping unit structure. The vibration behavior of a pumped off well will appear significantly different from that of a well with fluid over the pump. Monitoring pumping unit vibrations allows deviations from the desirable pump off condition to be identified early and timely corrective action scheduled to restore production, reduce power waste, and reduce the risk of further equipment damage.

MEOWS Phase I: Vibration Measurement
In the first phase, the study incorporated a small, off the shelf, self-contained wireless vibration sensor which was bolted to the pumping unit. The sensor was originally designed to track performance trends of rotating machinery. Signals induced by vibration of the pumping unit, which escalate during fluid pounding, were transmitted to a base station computer in the field office. The operator could then identify any problem wells by reviewing transmitted data.

The system chosen for the first study used patented (by the vendor), self-contained units that each included a vibration sensor, radio transmitter, circuit board, and 3 volt lithium battery in a weatherproof cylinder roughly 2 inches in diameter by 6 inches in length. The vibration sensor was a piezoelectric transducer employing a shear-sensing element and seismic mass to produce a charge output proportional to acceleration. For normal applications, the sample rate was set one per minute, which provided a battery life of roughly one year.

The radio was a low power (¼ Watt) unit with a range of up to ¾ of a mile. No special license was required as it operated in the 900 megahertz spread spectrum

range. For locations beyond the ¾ mile range, repeaters would have been employed. The radio base station interfaced with a PC where the vibration data were stored and processed. The lithium battery was serviceable.

During initial testing, the sensor units were installed on a total of four wells. Two of the wells were pumped off and two of the wells had fluid over the pump. The sensors were tested in both the acceleration mode and velocity mode. The sensors were positioned both vertically and horizontally on the polish rod and at the end of the walking beam near the horsehead. The installation of the units required less than 5 minutes per well and merely involved placing a clamp on the polish rod or threading the support base onto a mounting stud welded or glued to the walking beam. Due to the self contained nature of the sensor, no special wiring or skilled installation was required.

Statistical analysis of the vibration data was made including median, mean, and standard deviation. Statistical analysis of the velocity data were not useful in determining when the well was pumped off. However, analysis of the vibration data demonstrated that acceleration sensors were able to detect "fluid pound" when the well is pumped off. Median values for the acceleration data were less than the mean for pumped off wells, but similar for the wells with fluid over the pump. Based on median/mean and standard deviation, vibration acceleration measurements could be used for confirming that a well is operating in a pumped off condition. Results indicated that wells which are not pumped off have vibration behavior which fits a normal distribution, while pumped off wells have variation in vibration acceleration which consistently exceeds 2 and 3 standard deviations more frequently than expected in a normally distributed system.

The subsequent phase (MEOWS Phase II) was planned to include more wells and to incorporate improved statistics to analyze the field data, to further evaluate the best type of sensor to use, the best sensor location, the best sensor orientation, minimum sensor frequency, and minimum sample rate. Additional work was planned to evaluate the use of solar cell to eliminate battery service, and the use of radio transmitter repeaters to extend the transmission range. Low cost radio receiver connected to a smart computer in the pumping unit power box that can provide automatic pump off control was planned. Also, alternative sensors such as non-invasive ultrasonic flow meters, temperature probes, and/or pressure transducer were added to be investigated.

Petrolects, LLC, petroleum engineering consulting company, (www.petrolects.com), was contracted by Vaquero Energy to be the sole subcontractor on Phase II. Petrolects, LLC, was partially involved in Phase I of the

project. Vaquero Energy, in cooperation with Petrolects, LLC, submitted a proposal to Department of Energy for Phase II and was awarded a grant in 2002.

MEOWS Phase II: Real Time Flow Assisted Surveillance and Flow Signatures

The original concept was to utilize inexpensive but effective remotely monitored surveillance devices, wireless transmitters (if needed powered in some cases by solar cells), computers and software, to gather and analyze individual well system performance data in real time. As a result of that, the project was implemented to evaluate, install and test state-of-the-art remote monitoring equipment including wireless transmitters, computers, and software that could remotely sense, record, and analyze a key well system performance indicator. The benefits of the system would include:

> 1) *increased oil production*
> 2) *reduced well servicing costs*
> 3) *reduced electricity costs*
> 4) *reduced well testing costs*
> 5) *reduced manual surveillance costs.*

Increased Oil Production

The new system would allow real time detection of well production system failures. Compared to manual surveillance, this means the cycle time between failures and repairs will be greatly reduced. For producers higher than 10 bopd, this will range between 1 and 10 days. For producers lower than 10 bopd, this will range between 5 and 100 days. On average, it is expected that production rates will average at least 3% higher via elimination of "lost production" associated with undetected well production system failures. For Vaquero Energy's Edison Field, Main Area operation in Kern County, California with around 200 active wells, this improvement would be at least 720 BOPM (bbls of oil per month) over the current average of 24,000 BOPM.

Reduced Well Servicing and Electricity Costs

Although Vaquero Energy's wells all have digital time clocks to automatically stop and start the wells to reduce power consumption, the average pump efficiency is still very poor and is in the range of 10-20%. The new system would provide feedback to the operators for manual optimization of time clock "on/off"settings in the form of (1) proper total daily hours "on", (2) proper number of daily pumping cycles and (3) proper ratio between "on" vs. "off" time for each pumping cycle. For most of the Vaquero Energy wells, this would result in a large increase in pump efficiency and cause:

1. 10% reduction in electricity costs (~$2000/month)
2. Reduced wear, lower failure rate, longer life for each well's pumping system (~10%)
3. Reduced well servicing costs (~$2000/month)

Additional Forms of Increased Production
Some wells are expected to have time clock hours set too low. The new system would allow identification of these wells and after time clock hours are increased, a 10% increase in production is likely (240 BOPM).

Reduced Well Testing and Manual Surveillance Costs
Ideally, the new system would track a key well system performance indicator that correlates directly to well tests. This in turn would cause a reduction in the number of well tests required for each well annually. Vaquero Energy's well test costs include labor, bottled make-up nitrogen, and test vessel maintenance labor and parts. Reductions of $2000 per month are expected in the area of reduced well tests. Manual surveillance of wells involves visual inspection of each polish rod and well site each day and manual confirmation of expected fluid pound ("hit") level for each of the high rate producers (higher than 10 bopd). It is expected the new system would provide a total reduction of 24 daily man hours associated with the tasks (~$2000/month).

Environmental Benefits
Additional environmental benefits resulting from utilizing the MEOWS system would include lowered greenhouse gas emissions due to reduced power consumption by the more efficient pumping units and reduced automotive traffic for visual inspection. (A planned, future addition of a pump off control feature (currently in a preliminary design and testing stage) to the unit will increase these savings even more.)

Prototype Development
Three performance indicators of the pumping unit were investigated: Vibration behavior during pumped off and non-pumped off operating conditions, acoustic signature of the pumping unit and associated equipment during operation, and flow signature of well fluid during production operation. Flow signature of the well fluid was selected as the method to investigate further. The first two methods were rejected because: 1) no conclusive data could be obtained, and 2) in case of good data, the cost of equipment would have been prohibitive. It was therefore decided to design, build, and test a prototype system which uses a novel method of measuring the flow coming out of a well; automatically interprets the flow readings to provide easily interpreted readings of the relative efficiency of any well

production system including beam pumps; transmits these readings via wireless link to a field office; and allows for the addition of a fully automatic pump motor control system or pump-off-controller (POC).

Invention

On July 24, 2003, an invention was conceived which led to the prototype described above at Dr. Medizade's residence while Petrolects personnel were working on the project. Subsequently, patent proceedings were initiated with lawyer Philip A. Steiner, located at 846 Higuera #11, San Luis Obispo, California, 93401. The disclosure of the invention that was mailed to the Chicago office of the DOE was prepared with the assistance of Mr. Steiner. Subsequently a patent was applied for on January 16, 2004. At the time of the invention, two individuals were working at Petrolects, LLC. These two individuals are Dr. Mason M. Medizade, President of Petrolects, LLC and Dr. John Ridgely, Lead Engineer. Dr. Medizade has a background in Petroleum and Chemical Engineering. Dr. Ridgely has a background in Mechanical Engineering and specializes in Mechatronics.

Executive Summary

This DOE supported project has directly led to the invention and development of a novel Marginal Expense Oil Well Wireless Surveillance (MEOWS) monitoring system prototype to improve operating efficiency of rod pumped oil wells. Many rod pumped wells produce less than about 10 barrels of oil per day and are economically marginal. The economics of a marginal well are highly sensitive to the price of oil and cost of production; without improvements to production efficiency, marginal wells often must be shut down or risk operating at a loss. The MEOWS system allows marginal wells to be remotely monitored on a daily basis at low cost and provides information for improving efficiency of timer-controlled rod pumps. Currently, three prototype surveillance units are in operation in Edison Field, Main Area on wells operated by Vaquero Energy.

The MEOWS system has been developed during a four-year effort primarily funded by the Department of Energy. During the first two years of the study, small self-contained wireless vibration sensors were attached to different sections of rod pump units. Signals induced by vibration of the pumping unit during fluid pounding were transmitted to a base station computer in the field office. The operator could then identify problem wells by reviewing transmitted data. Statistical analysis of the vibration data was performed which demonstrated that acceleration sensors were able to detect fluid pound when the well was pumped off. Problems encountered during testing of the vibration detection system included high power usage which led to short battery life, and the high cost of the sensors.

In the third and fourth years of the MEOWS project, the method used to detect the pump-off condition was reevaluated in an attempt to overcome the most serious problems encountered during the first phase. Three methods to determine the operating condition of the pumping unit in real time were tested and compared: vibration measurement, acoustic emissions from surface equipment, and flow measurements of fluids produced. The third method was determined to hold the most promise for a reliable, economical, easily installed well operation sensor and was chosen for further investigation.

A method of detecting outflow from a beam pump was conceived by the investigators and a surveillance system designed to suit the advantages of this method: simplicity, reliability, direct monitoring of production, and low cost. A patent is currently pending on the proprietary method of flow detection. The flow sensors are integrated into a Well Pump Surveillance Unit (WPSU). Each WPSU

contains an inexpensive microcontroller and a 900MHz spread-spectrum radio modem which transmits readings to a base station located in the field operations office. At the base station, readings are compiled in software to a form which is easily interpreted by operations personnel and displayed in tabular or graphical format. Data is also archived for future reference.

The primary contractor plans future work to develop an automated Pump-Off Controller (POC) which uses flow indications from the MEOWS sensor for automatic control of the beam pump. Such a controller promises to provide the benefits of other state-of-the-art POC units at substantially lower cost, enabling the use of automated control on marginal wells which have heretofore not been profitable enough to justify the use of more expensive control techniques.

Hardware

The hardware for the system includes a set of Well Performance Surveillance Units (WPSU's) and a base station. WPSU's measure flow signature at each well in real-time. Sets of readings are stored and combined, then transmitted periodically to the base station. The base station is a single computer with radio modem which receives the signals from all the WPSU's. The base station then separates data received from all the WPSU's, processes the data for convenient inspection by operations personnel, tabulates the data and stores past data in archives for future use.

Well Performance Surveillance Unit (WPSU) Design
The WPSU hardware was designed to meet the following constraints:

1. Real-time functionality
2. Sensing and interpreting flow signals at the location of the sensor
3. High reliability and low maintenance
4. Long intervals between scheduled maintenance such as battery replacement
5. Ability to transmit data over moderately long ranges (1 or more miles)
6. Rapid prototyping to meet project deadlines
7. Low cost to manufacture and install

In order to meet the above constraints, the WPSU design incorporates a modern in-system reprogrammable microcontroller and a radio modem module, along with a proprietary flow sensor. Details of the system are described below. A more rigorous confidential description of the hardware is included within Appendix B. Appendix B will not be publicly released with this report but it is on file with the DOE, as this new technology is patent pending.

Sensor
The proprietary flow sensor design allows non-contact measurement of the flow state and can be integrated into existing well piping without disassembly of the pipe. A more rigorous confidential description of the flow sensor is included within Appendix B. Appendix B will not be publicly released with this report but it is on file with the DOE, as this new technology is patent pending.
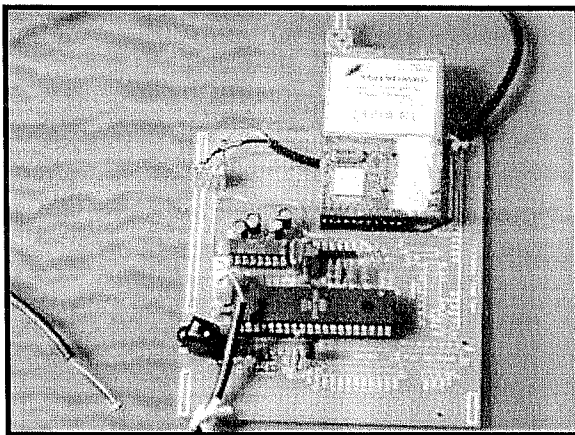
Microcontroller
There are hundreds of embedded control microprocessors (microcontrollers) on the market, and frankly, many of them would work acceptably in this application. The Atmel AVR (www.atmel.com) family was chosen for this application, mostly as a

convenience, as the designer had previous experience with this type of microcontroller. Support circuitry is minimal, consisting of about a dozen discrete devices, with another half dozen for the Palm™ PDA or radio modem interface (discussed below). The microcontroller systems were assembled on generic AVR-Project prototyping boards (www.avrproject.com). A key benefit of the AVR type microcontrollers is the capacity for in-system programming. When software updates are to be applied to a unit in the field, the new software can be transferred from a laptop computer to the microcontroller circuit in about a minute. Reprogramming via the radio interface would be a further improved method, but due to time and financial constraints this was not set up.

Radio Modem
Communications are performed by off-the-shelf radio modems from MaxStream™ (www.maxstream.net). Selected for their comparatively long range, reasonable price, high functionality and moderate power usage, the 9XStream(tm) model radio modems provide a range of up to 1-3 miles, transferring data directly between the serial ports of microcontroller and base station computer. Using channel-hopping techniques and implementing an internal collision avoidance mechanism, these radio modems are designed to be used in a networked environment which may include hundreds of devices within the same region of coverage. The units chosen are transceivers which allow data to be sent from the base station to the WPSU's. Bi-directional communication has not yet been implemented in software but is planned for future work. The unidirectional communications currently implemented simply carry sets of data from the pump units to the base station. The bidirectional capability of the radio modems *is* utilized internally by the modems, however, to ensure more reliable communication. A photograph of the radio modem and microcontroller circuit boards is shown below.

Photograph 1: Microcontroller and radio modem circuits

Power

The microcontroller and radio system uses an average current of about 100 micro amps and is powered by a set of five alkaline cells. "D" size cells were chosen for their high energy capacity. In theory, these cells should power the microcontroller and radio modem for about three years before needing replacement – this figure is found by simply calculating the time taken to deplete the energy in the battery. However, the current drain follows a sharply varying pattern, with a very low consumption by the microcontroller and much higher current usage when the radio is activated. It has been seen during testing of similar systems that only a fraction of the full capacity of the battery is reached before the system fails to function. A more reasonable prediction of the battery life of the prototype system as currently implemented is about one year. As the systems will remain in the field assisting Vaquero in monitoring their wells for some time, it is expected that a more accurate measurement of the battery lifetime will be available soon.

Prototype Recording WPSU's

For early tests, four WPSU's were constructed which lacked radio modems but instead used Palm™ PDA's to record data. Placed on four wells, these units saved data each time a signal was received from the flow sensor. The data was transferred to a personal computer and processed to produce graphs showing the behavior of a pump over a day. Example graphs are shown in the Results section below. Each recording unit contained a microcontroller circuit, similar to the final prototype circuit, powered by a single 9 volt battery which lasted for about three days. The microcontroller's RS-232 serial output was connected to the PDA, and saved by software which is discussed below. Each PDA was modified to be powered by two D-size alkaline cells instead of the AAA cells for which the PDA's were designed. This allowed the units to safely save data for several days.

Enclosures

Due to the harsh environment common to most oilfields, the WPSU's need to be protected from the elements Each WPSU is therefore enclosed in a simple case made of a length of four-inch PVC or ABS plastic drainpipe with plastic caps on the ends. With self-heating of the electronics not an issue due to the very low power loss, ventilation needs not be provided, and sealing wires to the outside world is accomplished with a small quantity of epoxy. For the prototypes, the plastic cases are then attached with stainless hose clamps to a convenient portion of the flowline. Radio antennas are enclosed within the plastic pipe. Several versions of the enclosure have been tried at different wells. In one version, the microcontroller and radio modem are mounted together within a short (approximately one foot) section of pipe, and a wire connects this unit to the

sensor. Oilfield personnel have recommended against such a design, noting that the wire is vulnerable to damage from accidents, vandalism, and even rodents. Therefore, in later versions the microcontroller and radio enclosure is mounted directly atop of the pipe, with the sensor wire fully inside the plastic pipe. The enclosure is held in place by a bracket attached to the pipe, or by stakes driven into the ground. A more complete enclosure which extended down to the ground was also tried; its performance and appearance were good, but the cost of installation makes it less desirable for widespread use. A photograph of this enclosure is shown below. The sensor and radio are enclosed within the white pipe to the right of the photo. Note the height of the system. The extra height is necessary, in this specific location, to locate the antenna above the level of obstructions which block radio transmission to the base station. The well was surrounded by orange trees and next to a fence topped with barbed wire.
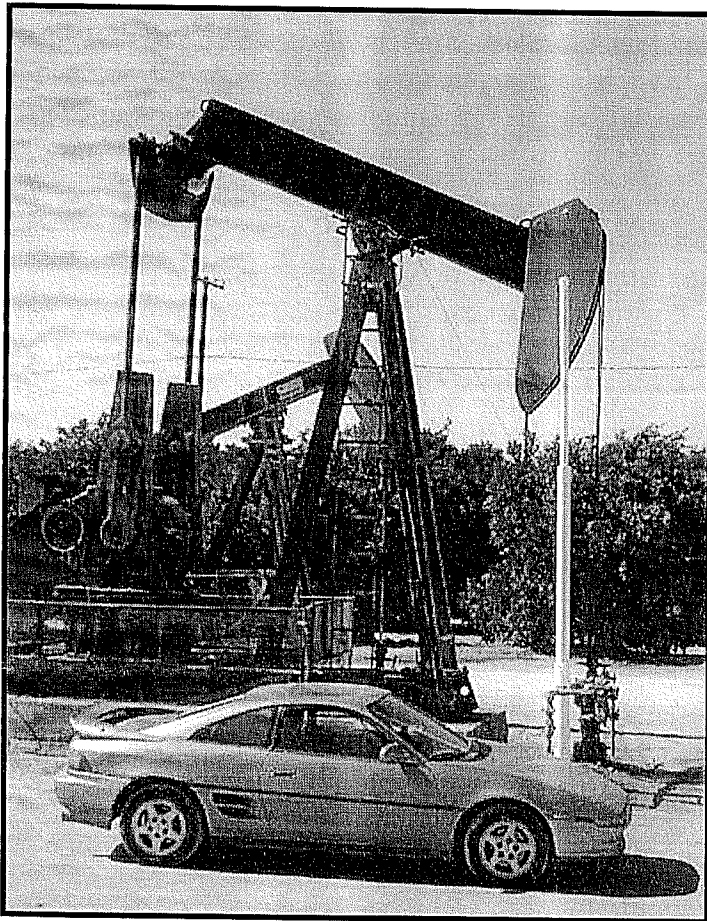
Photograph 2: WPSU Field installation

Base Station

The base station hardware consists of a radio modem interface with antenna, and a PC-class computer. The radio modem interface is located in an outdoor enclosure adjacent to the base station antenna, as shown in the photograph below.
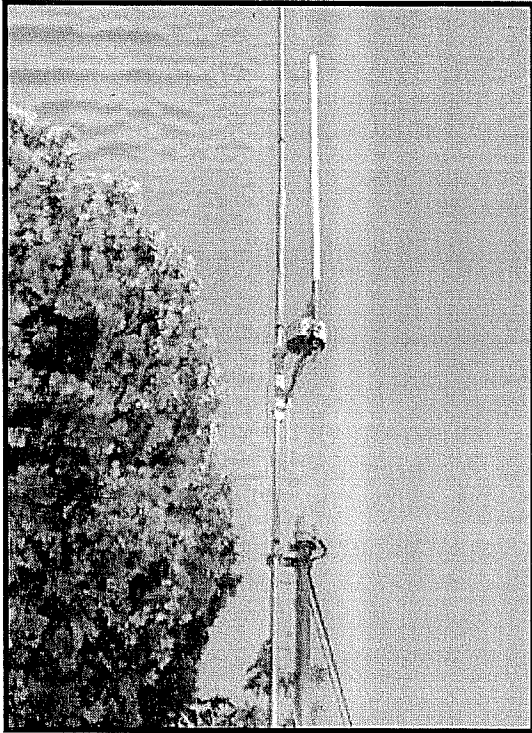
Photograph 3: Base station antenna and radio modem enclosure extending outward from mast. .

The modem interface consists of a MaxStream™ radio module of the same type that is used for the WPSU's. This radio module is mounted on an adapter board which interfaces the module directly to a PC's serial port. The serial connection from radio modem to base station is made through a standard, albeit somewhat long (50 foot), serial cable. The prototype base station computer is a Dell™ laptop. The laptop is used only for convenient prototyping; in future designs, a single-board embedded computer will provide a smaller and simpler platform. This is made possible by configuring the computer with the Linux operating system and enabling access via an Ethernet interface. The prototype computer is accessible via its network interface as a Web and file server. The Web interface is used to serve the daily well status summary pages described below in the software section; and the file server can be used to access archive data and to edit configuration files. For the prototype computer, the laptop's console is a convenient tool for software testing and debugging as well as for viewing the data.

Software

The project software consists of several parts:

1. WPSU software, running on the microcontroller
2. Base station software, running on a PC-class computer, generally located in the operator's office
3. Software for auxiliary devices used for testing and debugging

WPSU Software

The microcontroller in each WPSU contains internal program memory implemented in Flash RAM. This internal memory is programmed and reprogrammed in-system without the need for removing the unit from service, or for turning off the unit's power. Programs may be written in the AVR microcontroller's native assembly language or in higher languages such as C or C++. Because of the need for a rapid prototyping and debugging schedule, C++ was chosen for this project.

The first version of the pump units was designed to record information from the flow sensor over a 48-hour period in order to verify that the flow signal is a useful indication of pump activity. To that end, each microcontroller polled the state of the flow sensor and produced a signal at the microcontroller's serial port whenever the sensor's reading indicated the beginning or cessation of flow.

This signal was read by a Palm™ handheld computer which stored up all the readings during a test; the readings were then transferred through the same serial port to a PC for analysis. The handheld was programmed using the SuperWaba™ toolkit (www.superwaba.com.br), a Java™ work alike environment which assisted significantly in making the development cycle as short as possible.

Because battery powered operation requires minimal power usage by the processor, the WPSU software was written so as to place the processor in a sleep mode whenever computations were not actively being performed. In sleep mode, the processor's usage drops to a few micro amps rather than the several milliamps required with the processor active. Also, the radio modem is powered down when not transmitting. Given that the modem uses about 150mA during transmission, and transmission takes only a few seconds during each hour, it is critical to power up the radio only when needed.

In the current prototype system, readings are transmitted in a simple ASCII text format. An example reading, one line of several in a typical transmission, looks like the following:

P011 17:39:0 422 78

This line shows that the WPSU whose sensor is identified as number **011**, during the time period which began at **17:39**, recorded that a flow level of **422** was taking place. The maximum possible flow reading is fixed by the hardware and software configuration; in the configuration in which this line of data was recorded, the maximum possible reading was 960. The **78** is a checksum used to verify the integrity of the data.

Parameters which control the flow sensor reading, the number of seconds per sampling period, and the number of sampling periods' readings saved and transmitted in a batch to the base station are easily configurable in the program code. It is expected that in future revisions of the software, these parameters may be stored in separate non-volatile memory (most likely the EEPROM built into the AVR microcontroller chip) such that they may be changed during operation to best suit the requirements of the field operator.

Base Station Software
The software for the base station takes in the stream of data which comes from the WPSU's and produces daily statistics which are then presented on summary pages in an easily read HTML table. As this is primarily a text processing job, Perl was chosen as the language in which to implement the prototype system. It is expected that as the system evolves in the future, the software will be ported to a more general-purpose language such as Java™. For the prototype, the Perl scripts are automatically run on the base station's laptop computer by the cron scheduler. This ensures that at a predetermined time once a day (Vaquero Energy personnel asked for 5:45 AM), these scripts tally up the data for the past 24 hours and produce the summary pages. Example summary pages are shown in actual format as tables on the next two pages.

MEOWS Current Data

Created on Wed Aug 25 05:45:03 PDT 2004

24-Hour Most Recent Data

Pump Name	Sensor Number	Average Flow	Average (No Zeros)	Standard Deviation
Young Fee 60	11	60.4	198.6	116.0
Hershey 69	10	57.4	147.6	74.8
Duff Shell 42	12	3.0	50.4	14.8

Table 1: Sample daily summary page

MEOWS History Data

Created on Wed Aug 25 05:45:03 PDT 2004

24-Hour Current and History Data

Pump Name	Sensor Number	Latest Date	Current Average	History Average	Current NZ Avg.	History NZ Avg.	Current Std. Dev.	History Std. Dev.
Hershey 69	10	8.0	57.4	68.2	147.6	145.8	74.8	76.9
Young Fee 60	11	8.0	60.4	71.8	198.6	211.1	116.0	128.8
Duff Shell 42	12	8.0	3.0	14.1	50.4	119.6	14.8	55.0

*Table 2: Sample history page showing the current value of
each parameter and average of data from past few days*

The data fields in the table are as follows:
1. The first column contains the well names as assigned by the field owner. The well names are determined from the WPSU sensor numbers by reference to a plain-text file which lists names and numbers; if a sensor is not listed the program proceeds as normal with "(No name)" in the pump name field.
2. The sensor number is as transmitted by the WPSU. If a new WPSU sensor is installed in the field, no configuration is needed for the base station software to begin displaying data from that unit.
3. The latest date in the history table shows when the "current" data was tabulated. The current and "history" data (from 2 days to 2 weeks previous) are shown for each of several measurements. The average value is the daily average percent of time the valve was seen to be open.
4. The "NZ average" is the average of all readings which were not zero. This allows data which was taken when the well pump was off to be ignored; for some wells it may provide a more useful indication of activity (and changes in activity) than the overall average.

Management by Exception (Flag, Alarm, Dashboard Dummy Light, etc.)
Also included in the MEOWS History Table is the daily vs. historical average of the standard deviation (SD) of the data. Comparing daily SD to historical SD provides a tabular "control chart" that will indicate when a well's performance has drifted "out of control". This measure of scatter in the data can help detect production system problems in early stages before they worsen and lead to catastrophic failures. For example, pump wear could cross a threshold where one or more key hardware components in the downhole rod pump (balls seats, plunger, etc.) have developed a leak which is minor and/or intermittent – in the early stages – but will slowly progress to complete failure. This type of problem could then be confirmed via manual operator troubleshooting, resulting in prediction of failures before they occur and scheduling of immediate repairs with very little loss of production or waste of electricity. This trend tracking approach is consistent with the growing industrial culture of condition-based maintenance practices. Also, operator time is focused on higher-value equipment troubleshooting tasks vs. lower-value routine, repetitive surveillance tasks.

Field Data

Recording WPSU Tests

The first tests were conducted using units which recorded duration of flow pulses. The recorded data were analyzed; produced graphs of the system's behavior were scrutinized to determine the most useful method of interpreting data from the flow sensor. The flow sensor software was designed based on these original data sets obtained from the WPSU's. An example set of graphs and a more rigorous confidential discussion of the software development is included within Appendix C. Appendix C will not be publicly released with this report but it is on file with the DOE, as this new technology is patent pending.

Wireless Tests

When the wireless system was put into service, longer test runs could be completed. Below is shown the plot of data from a week-long test.
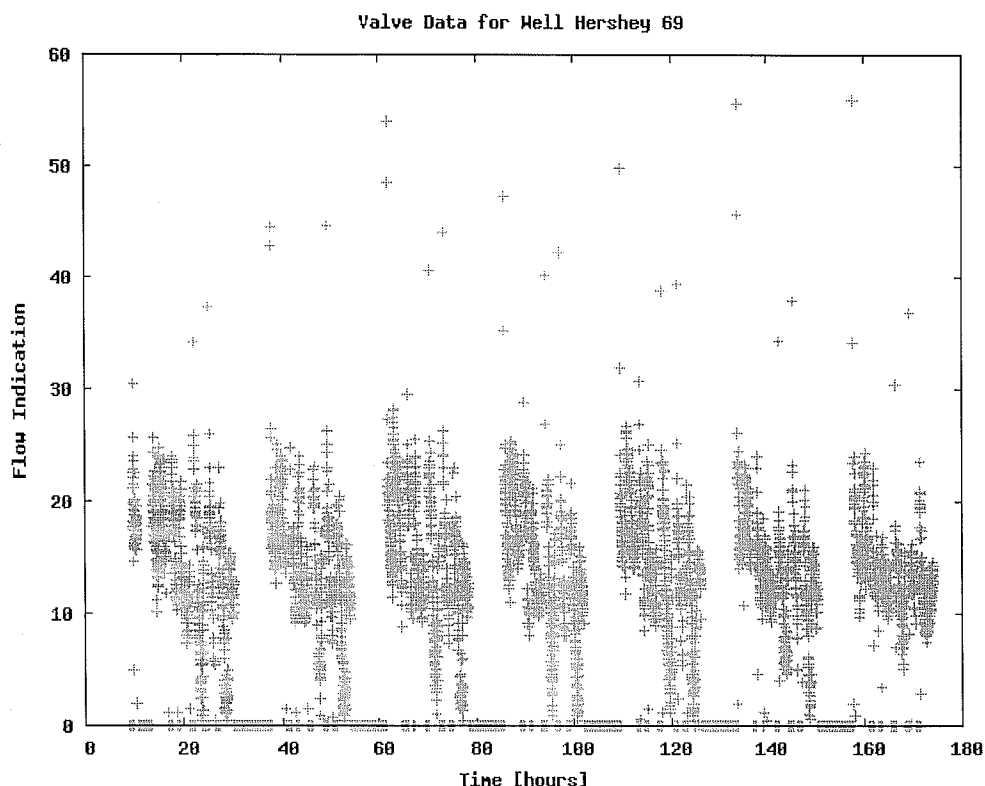
Plot 1: A week-long wireless test

It can be easily seen that this pump was running with a timer; the timer was set to turn the pump off during the peak demand period in the middle of the day between noon and 6 pm when power costs were very high through the time-of-use (TOU) meter. The decreasing trend in the data from the time the pump is turned on to when it's turned off indicates that the reservoir is losing some capacity to fill the pump during the on cycle. In other words, the pump system capacity is greater than the well's productive potential.

Tabular Output
For purposes of day-to-day monitoring, a field operator cannot afford to read through dozens or hundreds of graphs every day. For this reason the operators at Vaquero have requested tabular pages, examples of which are shown in the Software section of this report. For the approximately three weeks during which the three wireless systems have been in operation, these plots have shown output which hasn't varied very much, indicating trouble-free operation of the pumps (which was confirmed by the operations personnel). The exception is the data from two pumps which, surprisingly to the investigators, who had not been warned, suddenly dropped to zero readings indicating that no flow was occurring. It turned out, however, that the wells in question were being tested with a portable, two-phase, water-oil/gas separator, and for this test the flow sensors were being bypassed and cut off from fluid flow from the well.

Conclusions

In this study:

1. A low cost, real-time wireless surveillance system for monitoring production from oil wells produced via by sucker rod pumping units has been successfully designed and field tested. The system is applicable to any type of oil or gas well production method.
2. The heart of the unit is a proprietary flow sensor which is inexpensive and easily installed and connected directly to the flow line without trenching or need for outside power. The entire system is self-contained in the form of a Well Performance Surveillance Unit (WPSU). Due to planned commercialization of the system, a US patent has been applied for.
3. Hardware systems have been designed and built to withstand the high temperatures and variable and harsh climates typical of oilfields. This includes hardware needed on both transmitting (sensor) as well as receiving ends (base station).
4. Software has been designed (aka condition-based-monitoring, management by exception, red flag, alarm, dashboard dummy light, etc.) and implemented to convert and tabulate the signals from the flow sensor to meaningful numbers so the operator can easily know what the well is doing and take proper corrective actions.
5. State-of-the-art, high frequency radio systems specifically designed for high traffic in a limited area have been successfully employed.
6. Three surveillance units have been installed on wells in the Edison Field, Main Area of Kern County, California. Due to expiration of time on this contract, limited amounts of data (approximately six weeks' worth) have been obtained. Examination of the field data shows:

    (a) At what time a rod pump has started operation.
    (b) At what time a rod pump has stopped operation.
    (c) A relative measure of the production rate during the pumping period.
    (d) Evidence of fluid phase arrival on the surface, giving an indication of the presence of liquid (water and/or oil) vs. gas.
    (e) Ability to calculate the pump efficiency during each minute of the pumping operation.

It is the intent of the authors to report more system applications in publications associated with the Society of Petroleum Engineers such as the Journal of Petroleum Technology (JPT).

References

Nelson, D. G.: "Marginal Expense Oil Well Wireless Monitoring," paper SPE 62865 presented at the 2000 SPE/AAPG Western Regional Meeting held in Long Beach, California, 19-23 June 2000.

Appendix A
Alternative Test of a Wireless Water Meter

Vaquero Energy, the award recipient, tested an alternative off-the-shelf wireless system independent of the primary contractor Petrolects, LLC. The Vaquero Energy project director attended the International Agricultural Show in Tulare, California on February 11, 2004 to determine the potential for transferring commercially available low cost products from another industry into the "oil patch." About ten different wireless monitoring systems were considered by inspecting booth displays and discussing features with vendor representatives. A wireless crop monitoring system called Irriwise™ marketed by Netafim™ (www.netafimusa.com) was chosen for field testing. The system involves residential-type (nutating disk) water meters coupled with a low power radio transmitter; a base station receiver; and a base station PC with special software.

Vaquero Energy has prior experience with using nutating disk water meters as a low cost method to measure oil production from stripper wells with high water cut, low GOR, and 16 degree API oil production. It was found that the production rate and volume measurements are generally repeatable and accuracy is directly related to GLR (gas-liquid-ratio). Low GLR wells had more accurate results compared to high GLR wells. Accuracy determination is based on comparison of the nutating disk measurements to conventional well test methods through a two-phase liquid (water and/or oil) vs. gas separator.
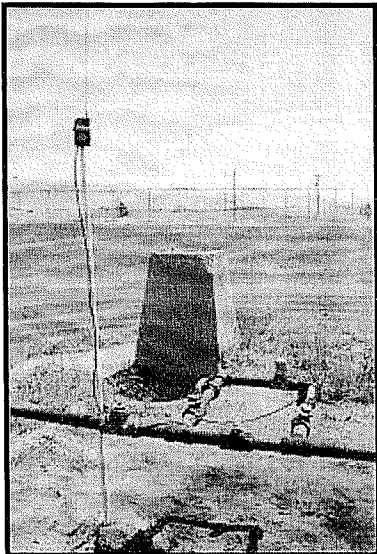
The meters chosen for testing have pressure limits of about 150 psi and were not advisable for hot applications present in cyclic steam oil production wells. The meters contain brass and the limits in cold environments were not investigated. Consequently, three meters were placed into service in a low pressure portion of the field on wells that were not scheduled for cyclic steam stimulation. The results were encouraging. The meters and radios worked and so far, have held up to oilfield conditions. Vaquero Energy plans to expand the test of the wireless water meters into more wells.

Netafim™ radio transmitter and water meter, component of the Irriwise™ Wireless Crop Monitoring System

Vi,
These are the two pie charts that I would appreciate your updating. (numbers and % only)
I asked Bruce to work up some recent numbers to correct the charts - He is working on it.

Susan Jackson has a recently updated pie chart for the micro hole project that would also be of interest.

Thanks for your assistance.
Jim

see pie chart 2, 4 & 5

File Pulling MT IOGCC
came from Roy's presentation

Sent Ver SPE
some slides from Roy IOGCC presentation
3, 7, 24 & 27

Get a NETL Oil gas internet slide (Roy's last slide)
use as final slide

Energy - consumption slide (Bruce)
2004